A Population Explosion: The Nature and Evolution of X-ray Binaries in Diverse Environments
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INTEGRAL and New Classes of High-Mass X-Ray Binaries

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Abstract. The gamma-ray observatory INTEGRAL, launched in October 2002, produces a wealth of discoveries and new results on compact high energy Galactic objects, nuclear gamma-ray line emission, diffuse line and continuum emission, cosmic background radiation, AGN and high energy transients. Two important serendipitous discoveries made by the INTEGRAL mission are new classes of X-ray binaries, namely the highly-obscured high-mass X-ray binaries, and the super-giant fast transients. In this paper I will review the current status of these discoveries.

1. Introduction

The ESA gamma-ray observatory INTEGRAL (Winkler et al. 2003) is dedicated to the fine spectroscopy (2.5 keV FWHM @ 1 MeV) and fine imaging (angular resolution: 12 arcmin FWHM) of celestial gamma-ray sources in the energy range 15 keV to 10 MeV with concurrent source monitoring in the X-ray (3-35 keV) and optical (V-band, 550 nm) bands. While the pre-planned scientific observing programme of the mission is driven by the usual Announcement of Opportunities with peer reviewed observing proposals, important *serendipitous discoveries* have also been made by INTEGRAL. Two of them are briefly described in this paper. Ingredients for new discoveries of point sources above 15 keV are: (i) a very large field of view of almost 900 square degrees, (ii) arc-minute source location capability, and (iii) a broad energy band with good sensitivity. In addition, long exposures and/or frequent monitoring of the inner Galaxy are provided through the general open time observing programme, the core programme (Gehrels et al. (1997), Winkler (2001)) and via the key programmes introduced recently. Nature, finally, contributes the highly variable high-energy sky. Monitoring the sky in the INTEGRAL energy range is of fundamental importance for Targets of Opportunities, multi-wavelengths follow-up observations and serendipitous discoveries.

2. HMXB and New IGR Sources

Recent hard X-ray sky surveys with INTEGRAL (Bird et al. (2007), Bodaghee et al. (2007), Krivonos et al. (2007)) have produced source catalogues containing between 400 and 500 detected point sources, covering energy intervals between 15 keV to 100 keV. These surveys differ slightly in sky coverage, energy range, time interval, detection criteria and detection software, but we can conclude that, on average, about 17% of all detected sources are HMXB (73 sources, on average) out of which one third are new INTEGRAL gamma-ray (IGR) sources identified as HMXB. About 23% of all detected sources remain yet to be identified. In the following sections we will briefly describe the new HMXB classes as detected by

INTEGRAL: highly obscured HMXB and super-giant fast X-ray transients. Both classes are populated by binary systems, where the compact object is orbiting a massive early-type OB super-giant star. These systems contribute to about 20% of the Galactic HMXB population, while the remaining 80% of HMXB are binaries involving a compact object orbiting a Be star.

2.1. Highly Obscured HMXB

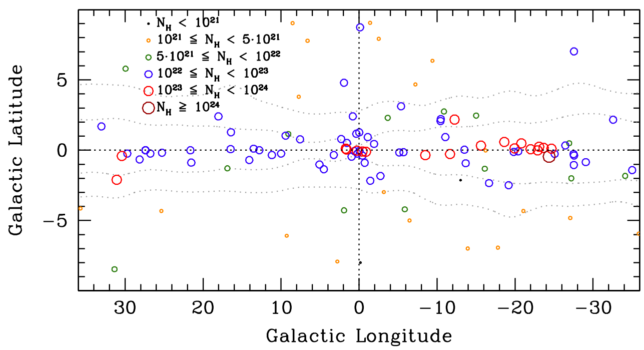

Figure 1. Spatial distribution (inner Galaxy) of all galactic sources (mostly HMXB) detected by INTEGRAL, for which N_H has been reported. From Bodaghee et al. (2007).

IGR J16318−4848 was discovered by INTEGRAL on 29 January 2003 (Courvoisier et al. 2003), shortly after the start of the nominal observing programme. The source is located very close to the Galactic plane (30′ off), and it was found that strong absorption below 5 keV ($N_H \sim 2{\times}10^{24}$ cm^{-2}) is dominating the spectral distribution of the HMXB with a compact object enshrouded in a Compton thick environment (Walter et al. 2003). Subsequent long term monitoring confirmed that the source remained bright and Compton thick (Ibarra et al. 2007). Using data from XMM-Newton, ASCA and RXTE, more INTEGRAL detected IGR sources with similar broad band "highly absorbed" spectra could be identified (Lutovinov et al. 2005). How many of these sources have been detected (until end 2006) by INTEGRAL? The recent survey by Bodaghee et al. (2007) displays, as shown in Fig. 1, the spatial distribution of all Galactic sources (mostly HMXB) detected by the imager IBIS onboard INTEGRAL for which N_H has been reported. If we define "highly absorbed" as local absorption in excess of ISM absorption in the line-of-sight, that is $N_H > 10^{23}$ cm^{-2}, then we conclude from Table 1 in Bodaghee et al. (2007) that out of 25 HMXB meeting this criterion, 16 sources (64%) are new IGR/HMXB sources, and 9 sources (36%) have been known previously. The "typical" source geometry and population characteristics are as follows: (i) a compact source embedded in dense material; (ii) the fluorescence region is larger than the orbital radius; (iii) spherical geometry; (iv) unknown or weakly detected in X-ray surveys prior to INTEGRAL; (v) strong low energy absorption $N_H > 10^{23}$ cm^{-2}; (vi) predominantly located in the Galactic bulge and along the Norma/Scutum spiral arms; (vii) long spin periods (typically 100 s to 1300 s) characteristic of wind accretion; (viii) short orbital periods < 10 days; (ix) early type stellar super-giant companion (Walter et al. (2005), Bodaghee et al. (2007)). In summary, the absorbed systems − a new class of HMXB − form the majority of active super-giant HMXB in our Galaxy. Thanks to the large increase of known HMXB in the inner Galaxy, it is now possible to study the HMXB spatial distribution in the inner Galaxy and to compare it with the location of star forming regions and spiral arm patterns (e.g. Lutovinov et al. (2005), Bodaghee et al. (2007)).

2.2. Super-Giant Fast X-Ray Transients

Thanks to the "ingredients" mentioned in the introduction, another (sub)class of HMXB previously hidden throughout the Galaxy could be identified with INTEGRAL: the super-giant fast X-ray transients (SFXT). While X-ray transients in general exhibit variations on timescales from few days to weeks or months, the SFXT are characterized by short outbursts lasting typically up to a few hours. Before INTEGRAL, the nature of these transients was largely unknown (see Sguera et al. (2005) for a summary). With INTEGRAL it was possible to detect new SFXT; detect for the first time recurrent outbursts, and associate SFXT with super-giant HMXB known to be persistent sources (Sguera et al. 2006). SFXT form a new sub-class of super-giant HMXB and we can assume that there are many more SFXT in our Galaxy as previously thought. The origin of the fast outburst, during which the persistent luminosity of $\sim 10^{32}$ erg/s increases by about 3 orders of magnitude is not firmly established: sudden accretion of small ejections originating in a clumpy wind, outbursts near or at periastron, or due to a second wind component (equatorial disk) of the super-giant donor (see Sidoli et al. (2007) for a discussion). Up to now (October 2007), eight firm detections of SFXT[1] exist with 20 more candidates under current investigation (Sguera et al. (2006), Bird et al. (2007), Bodaghee et al. (2007), Bazzano (2007)).

3. Conclusions

INTEGRAL discovered new classes of highly absorbed HMXB and SFXT, thanks to its large FOV combined with a broad energy range, fine imaging, good sensitivity and observing strategy. Long term monitoring with a large FOV is crucial to further enlarge the database. The new discoveries also pose new problems to be addressed by future observations: Why do we find highly absorbed HMXB as slowly rotating neutron stars with modest magnetic fields only, but no cyclotron lines and no black hole candidates? How can we explain the fast luminosity increase of SFXT by about 3 orders of magnitude?

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[1] IGR J08408−4503, IGR J11215−5952, IGR J16465−4507, XTE J17391−3021, IGR J17544−2619, SAX J1818.6−1703, AX J1841.0−0535, and IGR J18450−0435